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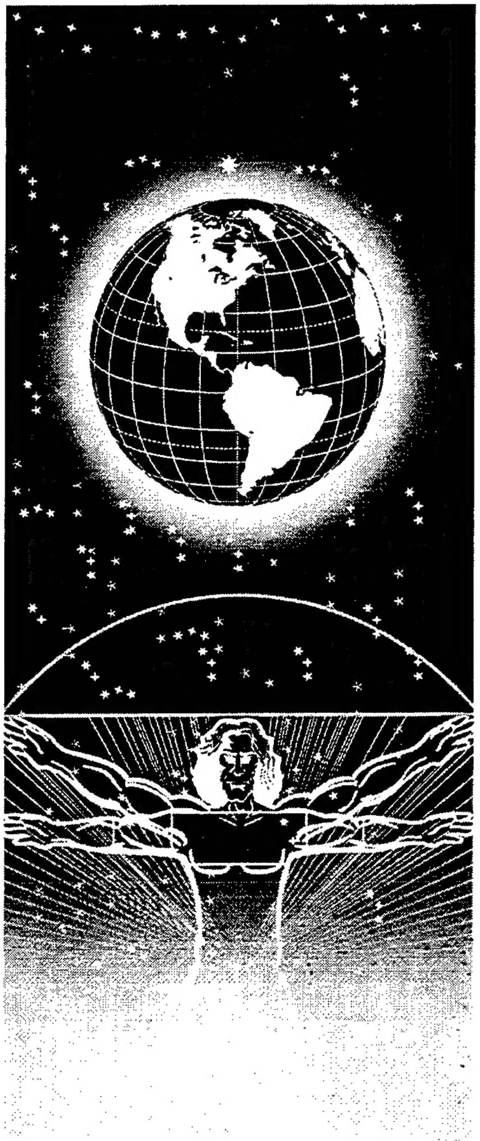

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Relationship Between Selected Measures of Physical Fitness and Performance of a Simulated Fire Fighting Emergency Task

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NOTICES

The voluntary, fully informed consent of the subjects used in this research was obtained as required by AFR 169-3.

This report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*

Two hundred and seventy-nine (males, n=272; females, n=7) career fire fighters between the ages of 19 and 58 volunteered for this study to determine the relationship between selected measures of physical fitness and performance of a standardized, strenuous task simulating fire fighting emergency activities. This task required the fire fighter to enter a military dormitory, proceed to the third floor, crawl 38.5 yds to reach a 170-lb victim, and drag him back to safety (the stairwell); time (min:sec) to completion was the performance criterion. Measures of cardiorespiratory fitness (VO2 max), muscular strength, and body composition were analyzed in an attempt to identify the fitness factors which contributed most to successful task performance. Age and all measures of fitness were found to be significantly correlated with performance. The time required to complete this task vs. VO2 max (n = 222) averaged 6:17 and 39.4 ml/kg/min, respectively. The top 25% (n=56) and the bottom 25 % (n=55) performer's times and VO2 max averaged 3:15 and 45.5 ml/kg/min, and 11:42 and 34.1 ml/kg/min, respectively. A regression model was presented which provides a reasonably good prediction of task performance as a function of % body fat, strength, and V02 max.

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INTRODUCTION

Fire fighters must, at all times, be prepared to respond to fire and rescue emergencies, and nearly always under the stress imposed by a critical sense of time urgency. Some of these emergencies, particularly those on the fire ground, impose high levels of physical exertion in environments that are often hazardous and life-threatening. Simple observation of emergency task activities is sufficient to conclude that a successful performance can depend, in large part, upon the physical capabilities, i.e., physical fitness of the responding fire fighters. Several investigators have monitored fire ground activities in an attempt to define the specific physical requirements which correspond with success in the performance of fire and other emergency services tasks. Barnard and Duncan[1] monitored heart rates of fire fighters responding to actual fire emergencies and reported values from 150 to 190 beats per minute (bpm) which were often sustained for several minutes or more. Lemon and Hermiston[2] measured the metabolic requirements of fire fighters performing tasks simulating fire fighting activities and reported values as high as 3.0 liters per minute (or 39 $ml \cdot kg^{-1} \cdot min^{-1}$ for a 170 lb fire fighter) of oxygen consumption ($\dot{V}O_2$) during relatively brief, but strenuous rescue tasks. Sharkey[3] studied wild land/forest fire fighters and reported $\dot{V}O_2$ requirements averaging 22.5 $ml \cdot kg^{-1} \cdot min^{-1}$ for intermittent activity (i.e., tasks that alternated very heavy with lighter activities, but averaging 22.5 $ml \cdot kg^{-1} \cdot min^{-1}$ in oxygen requirement for extended periods of time). Others[4,5] have supported the conclusion that aerobic capacity is indeed a predictor of one's capability to successfully perform strenuous fire fighting tasks, and they have also emphasized the obvious role of muscular strength in meeting these performance objectives.

It is not necessary to debate the fact that physical fitness is a major prerequisite for the successful performance of strenuous and sustained fire fighting tasks. Other things being equal, the fact that the fire fighter with the highest level of physical fitness offers the rescue victim the best possible chance of survival is unequivocal. However, attempts to establish minimal standards for cardiovascular capacity and muscular strength for fire fighters remain embroiled in controversy. Indeed, it is paradoxical that there is some evidence that neither civilian[4] nor military[6] fire fighters are physically more fit than the average for males of all ages. More work is needed to strengthen the evidence that physical fitness must not be compromised as a condition of employment in this career field.

The purpose of the present study was to identify a task that realistically represents fire fighting activities that can be expected of any fire fighter, and then to attempt to define the relationship between measures of physical fitness--that can be safely and validly administered by fire department personnel--and performance of a simulated fire fighting emergency task. If it is possible to establish this relationship, i.e., that a given level of physical fitness can predict a given level of performance, then agreement among experts in fire protection, with respect to the lowest acceptable level of performance, can be used to establish the minimal fitness requirements for career fire fighters.

METHODS AND PROCEDURES

Subjects

Two hundred eighteen male and four female career fire fighters representing one Army and seven Air Force Base fire departments volunteered to participate as subjects in this study. All had previously completed medical physical examinations required prior to assignment (military personnel) or employment (civilian personnel) in the fire fighting career field, an occupation where the protection of human lives as well as the protection of high-cost items of military inventory may be directly dependent upon each individual's physical ability to perform strenuous emergency tasks under the severest of environmental conditions and hazards. Following a group discussion and a demonstration of all tests and procedures, each signed an informed consent to participate in this study. Subjects consisted of the

normal mix of fire department employees in that some were on a 40-hr per week work schedule (i.e., 8-hrs per day), but most worked a 24-hr shift and accumulated 72 work hours every week.

Baseline measures: The fitness tests selected were those that not only could be used to validly assess both cardiovascular capacity and muscular strength, but were also practical in the sense that they could be safely administered by non-technically trained department personnel without the need for additional medical clearance and/or supervision. All baseline measures were obtained during each department's normal test cycle. Subjects were tested at either (1) 0530 to 0730 hrs, after spending the night in the station dormitory, or (2) immediately after roll call at the beginning of their work day (i.e., at 0745 to 1000 hrs). Measures of aerobic capacity were obtained for all subjects, and measures of muscular strength and endurance were obtained from most, but not all, dependent upon subject and equipment availability in the field. These measures, which are described in detail in AFP 92-3[7], included the following:

<u>Aerobic capacity</u> was estimated from heart rate response to sub-maximal cycle ergometry as described by Myhre[7-9].
<u>Muscular strength</u> was determined by one-time maximal lifts for the bench press, upright forearm curl, and upright rowing. Leg strength was measured as a one-time maximal lift on the leg press according to equipment availability.
<u>Muscular endurance</u> was taken as the number of times the fire fighter could raise and lower an 80-lb barbell from the bench press position at a rate of 30 lifts per minute.
<u>Body density</u> was determined by hydrostatic weighing as described by Myhre and Kessler[10], underwater weight was corrected for residual lung volume which was measured by nitrogen dilution as described by Allen[11].
<u>Percent body fat</u> was calculated from body density by the method of Keys and Brozek[12]. Estimates of percent body fat were obtained from circumference measures according to Hodgdon and Beckett[13] when either facilities or subjects were unavailable for underwater weighing. Lean body mass was calculated as the difference between total body weight and fat weight.

Fire fighter task performance: The fire departments participating in this study had implemented fitness training and performance testing programs, both of which were mandatory for all fire fighters. The fitness program was as described in AFP 92-3[7], and the performance tasks had been developed by Strategic Air Command (SAC) fire chiefs to simulate emergency activities that they considered representative of the most critical performance requirements for their fire fighters. These tasks, which included (1) B-52 "crash" aircrew rescue, and (2) structural search and rescue activities performed in either a multi-story smokehouse or in a standard air base dormitory, had become a part of each department's routine training program. The structural (dormitory) task was selected for observation in this study because it lent itself well to standardization under reasonably well-controlled conditions, and because of the justified concern for potential damage to aircraft should they be subjected to repeated exercises of this nature. All studies of fire fighter performance of simulated emergency tasks were coordinated with each Base Hospital Commander who provided on-site medical supervision during this phase of the data collection.

The SAC structural search and rescue scenario was modified only slightly to facilitate standardization which would allow a meaningful comparison of performance scores. This was deemed necessary not only for comparing the performance of fire fighters at a given air base, but also to allow the comparison between fire fighters at different bases (each with dormitories of similar construction). This exercise can be described as follows:

<u>Structure</u>: Three-story dormitory. Main entry leads to both the first floor hallway and the stairwell. Two flights of 16 stairs each lead to the third floor where a fire door separates the dormitory hallway from the third floor landing. The hallway floors in the Air Force dormitories were covered with a short-pile carpet; in the Army dormitory the floor was covered with vinyl tile. The longest distance from the stairwell door to the end of the hall was just over 40 yards. (In one series of experiments involving

16 fire fighters the structure was limited to an exterior hallway which precluded maneuvering the "victim" from the hallway through a fire door and onto a stairway landing.)

"Victim": Fire fighters volunteered to alternate as simulated victims for these exercises. A turnout coat was worn over their normal day uniform, additional weight was added when necessary to bring their clothed weight as near as possible (± 2 kg) to the selected standard of 77 kg.

Fire fighter: Fire fighters wore their standard protective ensemble which included a 30-min pressure-demand self-contained breathing apparatus (SCBA), over their normal day uniform. In addition, they carried two lengths of hoseline and a water thief which they deposited on the third floor landing during the first phase of the performance task. The weights of these extra burdens were as follows:

Protective Ensemble	Weight (kg)*
Day uniform:	3.31
Turnout coat, trousers, helmet, hood, gloves, and boots	7.58
SCBA (fully charged)	11.34
Total ensemble weight	22.23

[* Differences in weight as a function of uniform size were ±< 2 kg.]

Equipment Carried**	
100 ft of 1-1/2 inch hose line (bundle)	18.15
50 ft of 2-1/2 inch hose line (bundle)	13.61
Water thief	5.90
Total equipment weight	37.66
Total burden over nude weight	**59.89**

[**For Army tests, the burden carried was a "high-rise" kit weighing 26.5 kg making the total burden only 48.73 kg]

Rescue scenario: Wearing the full protective ensemble and packing the equipment burden described above, the fire fighter stands "ready" 10 yds from the dormitory main entry. The fire fighter advances on command as quickly as would be prudent for safety through the opened doorway, on to the stairwell and stepping on each stair up to the third floor landing. Upon reaching the landing, the fire fighter drops the equipment carried, activates the SCBA and enters the hallway through the opened fire door. Once in the hallway, the fire fighter crawls directly to the "victim" who is lying on his back , his head exactly 38.5 yards from the fire door and with his feet toward the other end of the hall. Upon reaching the victim, the fire fighter grasps the belt or rope positioned under the victim's arms and around his chest, and begins to tow the victim toward the stairwell door. (The fire fighter must keep at least one knee on the floor at all times, and the victim's head must stay in contact with the floor during the entire exercise.) The fire fighter continues to drag the victim until he is outside the hallway and resting on the third floor landing. The performance criterion was the time required to complete the task, and scoring for these tests was as follows:

Scoring a completed rescue effort: The rescue effort was separated into four components: (1) the time required from the start outside the building until the fire fighter reached the third floor landing; (2) the time required to crawl and reach the victim; (3) the time required to drag the victim the 38.5 yards to the stairwell landing; and (4) the total time required from start to finish. The total time was selected as the criterion of performance.

Scoring an aborted rescue attempt: In cases where a fire fighter was physically unable to complete the entire rescue task, the time assigned to the failure was a combination of (1) the time from the start until the point of failure; (2) then adding 60 seconds to represent a needed rest; and (3) the remainder of the time was calculated to be that which would have been required had the fire fighter been able to continue at the same rate that he/she demonstrated prior to quitting with exhaustion. Since the fire fighter would not be able to continue beyond the duration of his/her SCBA air supply, the maximum time allowed for any attempted rescue calculated in this manner was set at 30 minutes.

The fire chiefs had originally intended that, after bringing the victim to safety, the fire fighter would immediately return to the hallway and repeat this activity for a second victim. The first series of tests involving 57 fire fighters was conducted following this scenario. However, when it became evident that most (72%) were unable to complete the task in an acceptable time (10 minutes) and indeed a large number of them (47%) were unable to finish at all, it was agreed that the scenario be revised to require a single victim rescue which became the standard protocol for this study. Although the results of the double victim rescue experiments are not included in the main body of this paper, a summary of those data is presented in the Appendix.

Performance observations:

Performance time: Stopwatch time constituted the primary criterion of the simulated rescue task performance.

Exercise heart rate: The fire fighter was fitted with either Exersentry™ or Polar™ chest electrodes which transmitted EKG signals to a cardiotachometer attached to the outside surface of turnout coat. So as not to impede the fire fighter's rate of progress in any way, observations of heart rate were limited to the peak level observed immediately after reaching the designated goal at the completion of the rescue exercise.

Respiration rate: Respiratory frequency was calculated from a 15-second record of the easily audible inspiratory sounds (SCBA) during the middle portion of the drag segment.

Ventilation: The average ventilatory minute volume and the total liters of air (ATPD) required for the rescue were estimated from the loss of air pressure (psi) displayed on the SCBA air cylinder. Tidal volume was then calculated as a function of minute volume and respiratory frequency.

Data analyses: Descriptive statistics were used to define the sample population with respect to physical characteristics and task performance. Pearson product-moment correlations were computed to evaluate the relationship between each selected measure and the time required to complete a standardized simulation of a fire fighter rescue task. Least squares multiple regression analysis was used to develop a prediction model for task completion time.

RESULTS

The physical characteristics of the two hundred eighteen male and four female career fire fighters who participated in this study are summarized in Table 1.

Table 1. Summary of physical characteristics of fire fighters performing the structural rescue exercises (n = 222).

	Mean ±SD	Minimum	Maximum
Baseline Data:			
Age, years	30.4 ± 9.3	19	58
Ht, cm	178.6 ± 7.6	154.9	200
Wt, kg	83.5 ± 13.1	51.3	130.8
Body fat, %	20.1 ± 6.9	5.9	42.0

Table 2 presents a summary of the fitness characteristics and the levels of performance that these fire fighters demonstrated for the standardized Air Force structural rescue task .

Table 2. Summary of fitness scores and task performance data for subjects performing the standardized Air Force structural rescue exercises (n = 222).

	Mean	Std Dev	Minimum	Maximum
Fitness Parameters:				
$\dot{V}O_2$ max, $ml \cdot min^{-1}$	3221	748	1522	5611
$\dot{V}O_2$ max, $ml \cdot kg^{-1} \cdot min^{-1}$	39.4	9.8	18.8	65.7
Bench press, lbs	171.6	47.1	70	315
Leg press, lbs	399.6	93.7	200	750
Curl, lbs	89.3	22.6	40	185
Row, lbs	98.3	23.7	40	185
80 lb bench press, reps	29.7	12.8	2	74
Performance Data:				
Climb stairs, min:sec	0:37	0:10	0:15	1:26
Reach victim, min:sec	1:50	0:32	0:55	4:18
Drag victim, min:sec*	3:17	1:26	0:49	10:10
Total rescue time, min: sec	6:17	5:16	2:11	30:00**
Peak heart rate, bpm (n=110)	186.0	11.5	144	208
Ventilation, $l \cdot min^{-1}$ (ATPD)	104.6	31.3	40.5	288.6

*Calculated only for those (n=199) who actually completed dragging the victim to safety.
**Unable to complete rescue; time is calculated from the demonstrated rate of progress up to the point where the fire fighter gave up (see methods section for detailed explanation).

The strenuous nature of the rescue task, which required an average of 6 min 17 sec to complete, is evidenced by the mean values for ventilation and peak heart rate which suggest a near maximal effort for these fire fighters. (The mean heart rate of 186 bpm would be estimated to represent 98% of maximum for fire fighters averaging 30 years of age.) The data summarized in Tables 1 and 2 illustrate a relatively wide subject variability with respect to both fitness and performance scores, and this is fortunate for a study which attempts to identify factors which may be useful in predicting both high and low levels of task performance. For example, at one extreme is a fire fighter who was able to complete the entire rescue task in 2 min 11 sec. This outstanding performance can be contrasted by fire fighters who quit with exhaustion before even reaching the "victim" and were assigned the maximum allowable time of 30 min for their effort. It seems quite probable that these fire fighters, demonstrating the best and the poorest, respectively, of the 222 performance times, will also be found to rank among the best and the poorest of the sample with respect to one or more of the fitness measures studied. An empirical review of individual data may reveal some of the most obvious physical characteristics that relate to

performance of this simulated fire fighter operational task. To this end, individual data for the 5 best performers are contrasted with those for the 5 poorest performers in Table 3.

Table 3. Physical and fitness characteristics of the fire fighters with the five best performance times are compared with those presenting the five poorest performance times in the simulated single victim rescue task.

Age yrs	Weight kg	Fat %	$\dot{V}O_2$ max ml·kg^{-1}·min^{-1}	Bench P. lbs	80# BP reps	Curl lbs	Row lbs	Rescue Time min:sec	Heart Rate bpm
				The 5 Best Performers					
19	78.5	–	53.3	165	57	90	100	2:11	---
28	73.5	–	47.7	187	35	110	130	2:27	---
21	79.4	12.5	49.7	--	--	–	--	2:30	---
28	79.4	16.9	54.5	250	50	135	135	2:34	180
23	90.7	24.7	43.7	--	36	--	–	2:42	176
				Mean ± S.D.					
23.8	80.3	18.0	49.8	200.7	44.5	111.7	121.7	2:28.8	178
±4.1	±6.3	±6.2	±4.4	±44.1	±10.8	±22.5	±18.9	±11.4	±2.8
				The 5 Poorest Performers					
18	94.9	–	26.1	140	25	60	70	30:00*	–
47	77.8	--	25.4	120	13	60	40	30:00	–
45	100.9	--	24.9	–	–	--	–	30:00	--
49	79.9	30.8	27.1	130	23	70	90	30:00	–
56	82.5	37.6	21.5	180	25	70	90	30:00	--
				Mean ± S.D.					
43.0	89.2	34.2	25.0	142.5	21.5	65.0	72.5	30:00	--
±14.6	±13.8	±4.8	±2.1	±26.3	±5.7	±5.8	±23.6		–

*Unable to complete rescue; time is calculated from the demonstrated rate of progress up to the point where the fire fighter gave up (see methods section for detailed explanation).

Even before subjecting these data to discriminating statistical analyses, a simple inspection of the data available for the subjects selected for comparison in Table 3 suggests that there are fitness measures which clearly and significantly characterize, and thus separate, outstanding task performers from those who just as clearly failed in this event. From this small sample it can be noted that the best performers were younger (24 vs. 43 yrs), leaner (18 vs. 34% body fat) and exhibited higher scores in each of the fitness measures studied. Perhaps the most striking of the differences in fitness scores was that for aerobic capacity which averaged 49.8 vs. 25.0 ml·kg^{-1}·min^{-1} for the best and the poorest performers, respectively.

In a further attempt to identify task-relevant fitness parameters, the data for all subjects were arranged in rank order according to performance (i.e., from the fastest to the slowest rescue time), and were then divided into quartiles. Mean values for performance, physical characteristics, and fitness scores are presented in Tables 4 and 5.

Table 4. Physical characteristics of 222 career military fire fighters classified according to quality of performance (quartiles) of a simulated emergency rescue task.

Rank Performance Percentile	Rescue Time min:sec	Age yrs	Ht in	Wt lbs	Body Fat %
75 to 100	3:15 ± 0:25 (n = 56)	25.3 ± 5.4 (n = 55)	71.0 ± 2.7 (n = 54)	180.9 ± 21.2 (n = 55)	16.2 ± 4.7 (n = 45)
50 to 75	4:31 ± 0:23 (n = 55)	28.6 ± 8.1 (n = 52)	70.4 ± 2.9 (n = 54)	176.1 ± 20.7 (n = 54)	17.9 ± 5.5 (n = 42)
25 to 50	5:44 ± 0:25 (n = 56)	33.4 ± 9.5 (n = 54)	70.5 ± 3.0 (n = 55)	192.6 ± 31.4 (n = 56)	23.1 ± 7.0 (n = 44)
0 to 25	11:42 ± 8:23 (n = 55)	34.5 ± 10.4 (n = 54)	69.5 ± 3.3 (n = 55)	186.5 ± 36.8 (n = 55)	24.2 ± 7.3 (n = 33)

From Table 4 it can be seen that the top 25 percent of the performers were able to complete this task in an average of 3 min 15 sec; the best time achieved for this event was 2 min 11 sec. The poorest performance times included several fire fighters who quit before finishing the task. Indeed, some quit with exhaustion upon arrival at the top of the second flight of stairs, i.e., before they even entered the hallway where they were supposed to rescue a victim. The times assigned to those who failed to finish the task ranged up to a maximum of 30 minutes, but the average time for the poorest 25 percent of the fire fighters' performances was 11 min 42 sec.

Table 5. Physical fitness characteristics of 222 career military fire fighters classified according to quality of performance (quartiles) of a simulated emergency rescue task.

Performance Percentile	Aerobic Capacity $ml \cdot kg^{-1} \cdot min^{-1}$	Aerobic Capacity $ml \cdot min^{-1}$	Bench Press 80-lb reps	Bench Press max/lbs	Leg Press max/lbs	Curl max/lbs	Row max/lbs
75 to 100	45.5 ± 8.4 (n = 56)	3696 ± 709 (n = 55)	33.3 ± 11.6 (n = 44)	194.1 ± 42.9 (n = 39)	448.3 ±111.6 (n = 22)	105.1 ± 25.2 (n = 39)	112.9 ± 22.2 (n = 39)
50 to 75	41.8 ± 8.8 (n = 55)	3300 ± 698 (n = 54)	32.7 ± 12.3 (n = 43)	176.1 ± 43.8 (n = 41)	413.9 ± 87.0 (n = 34)	89.9 ± 17.0 (n = 43)	100.8 ± 19.9 (n = 43)
25 to 50	36.0 ± 8.7 (n = 56)	3074 ± 590 (n = 56)	27.7 ± 8.7 (n = 38)	164.5 ± 46.5 (n = 41)	377.8 ± 73.7 (n = 31)	85.2 ± 21.3 (n = 40)	95.7 ± 18.5 (n = 40)
0 to 25	34.1 ± 9.1 (n = 55)	2818 ± 896 (n = 55)	24.3 ± 15.9 (n = 39)	151.6 ± 46.5 (n = 38)	369.1 ± 91.4 (n = 29)	77.2 ± 17.5 (n = 39)	83.6 ± 24.9 (n = 39)

An empirical review of Tables 4 and 5 shows that these data are in agreement with the results indicated in Table 3, and support the hypothesis that performance time is correlated with the physical and fitness characteristics of the fire fighter. The better performers were younger, leaner, more aerobically fit, and stronger than their poorer performing counterparts. However, it is also quite probable that many of the fire fighters who find themselves situated somewhere between the extremes may share similar

performance times while varying greatly in one or more of the fitness parameters measured. The correlation analysis presented in Table 6 is an attempt to identify which fitness measures might best explain differences in the performance of this specific task.

Table 6. Pearson product-moment correlation (r) values for fitness and performance parameters.

Variable	Rescue Time	Bench Press	80-lb Bench Press	Curl	Row	Body Fat	LBM
Age	0.38	-0.23	-0.07ns	-0.25	-0.26	0.45	-0.01ns
$\dot{V}O_2$ max ml·kg^{-1}·min^{-1}	-0.36	0.28	0.28	0.21	0.22	-0.57	-0.01ns
$\dot{V}O_2$ max ml·min^{-1}	-0.33	0.38	0.36	0.33	0.30	-0.24	0.47
Bench Press	-0.18	1.00	0.65	0.66	0.65	-0.27	0.41
80-lb Bench Press	-0.17	0.65	1.00	0.50	0.50	-0.22	0.35
Curl	-0.25	0.66	0.50	1.00	0.72	-0.31	0.46
Row	-0.37	0.65	0.50	0.72	1.00	-0.30	0.38
% Body Fat	0.36	-0.27	-0.22	-0.31	-0.30	1.00	0.02ns
Lean Body Mass (LBM)	-0.21	0.41	0.35	0.46	0.38	0.02ns	1.00

[All correlations were significant at P<0.05 except where indicated (ns)]

From Table 6 it can be seen that age and all of the fitness parameters were significantly correlated with performance time. However, no single fitness variable appeared to be strong enough to suggest that it alone could predict performance capability. An R-square analysis, utilizing the least squares multiple regression technique, was performed to identify the best predictors of performance time. Table 7 shows the best 1-variable, 2-variable, etc., models.

Table 7. Regression models[a] for the dependent variable 'time' required to complete the standardized Air Force structural rescue task.

No. in Model	R-Square	Variables in Model
1	0.2289	%Fat
2	0.3567	%Fat; $\dot{V}O_2$ max, total ml·min^{-1};
3	0.4023	%Fat; $\dot{V}O_2$ max, total ml·min^{-1}; Curl, lbs;
4	0.4114	%Fat; $\dot{V}O_2$ max, ml·kg(LBM)$^{-1}$·min^{-1}; Curl, lbs;Wt., kg
5	0.4156	%Fat; $\dot{V}O_2$ max, total ml·min^{-1}; Curl, lbs; LBM, kg; Wt., kg;

[a]Data for the 16 fire fighters who performed this task in the non-conventional structure (i.e., exterior hallway with no fire door) and for the 23 fire fighters who were unable to complete the task were not included in this analysis.

Significant improvement is seen when using the 3-variable model compared to the 1- and 2-variable models. The 4-variable model does not significantly improve the fit over the 3-variable model. Consequently, the most efficient formula for predicting performance time could be achieved utilizing the following three variables: body fat, aerobic capacity in total ml·min^{-1}, and arm strength for the forearm curl. The prediction formula is:

$$\text{Predicted time (sec)} = 427 + 4.69\ (\%\text{fat}) - .03943\ (\dot{V}O_2\ \text{max, total ml}\cdot\text{min}^{-1}) - 1.02\ \text{Curl (lbs)}$$

Performance times estimated from the above formula are plotted in Figure 1 against times actually achieved by the 222 fire fighters participating in this study.

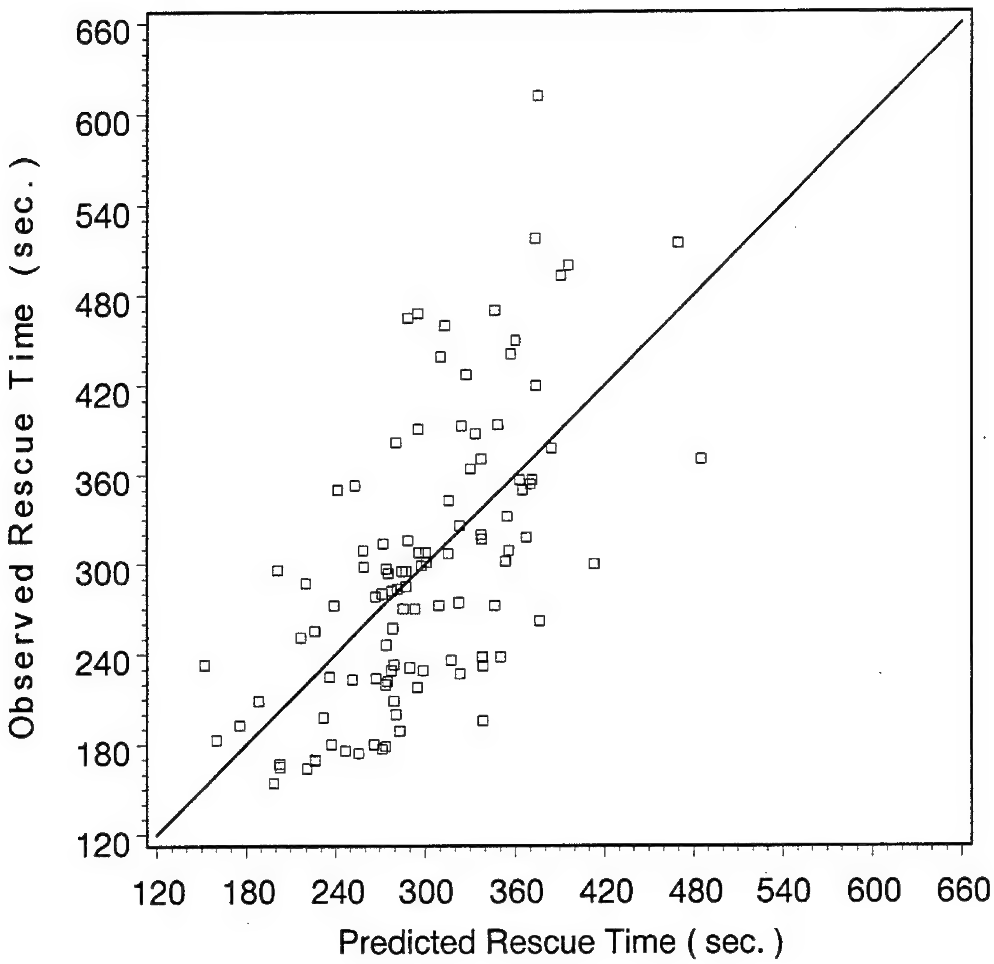

Figure 1. Predicted Rescue Time (from Regression Equation) vs. Observed Rescue Time for Military Fire Fighters

Human variability in task performance is undoubtedly not simply a function of the limited fitness parameters studied here. Still, as shown in Figure 1, measures of body fat, aerobic capacity, and arm (curl) strength can provide a reasonably good prediction of rescue task time.

DISCUSSION

Crash and structural rescue activities are given the highest priority for fire fighters in an emergency response. The time urgency assigned to these tasks is evident from the fact that success or failure, indeed life or death, can be separated not by the number of minutes, but rather by the number of

seconds required to extricate the victim from an extremely hazardous environment. For example, for the victim lying unconscious in an environment where the volume of a fire can be expected to increase logarithmically with time, where the temperature can be expected to exceed 450°F[14] within a matter of a few minutes, and where breathing air may contain 3000 ppm carbon monoxide[15], the time of exposure before rescue is very important and critical.

It is obvious from the near-maximal heart rates and minute ventilations observed here that rescue tasks are physically exhausting and the physical requirements for performing these tasks can exceed the present physical capabilities of even some of those who are employed as career fire fighters. In brief, if fire fighters are expected to be able to perform strenuous emergency tasks, the need for standards which assure fitness-for-duty is unequivocal. Establishing a fitness standard that can be defended as task-relevant as well as one which can be achieved by a significant proportion of the healthy adult labor pool presents an ongoing challenge to researchers in applied physiology and occupational medicine.

The present study demonstrated that a highly fit fire fighter engaged in a standardized structural rescue exercise could bring a simulated victim to safety in 131 seconds. It also showed that the 55 least physically fit fire fighters studied required an average of 702 seconds to complete this exact same task, and that several of them were unable to complete the task at all. Still, all of these subjects are fully employed as career fire fighters. Left to the victim, the choice of the fire fighter to perform the rescue task would be obvious, but it is doubtful that this career field is ready to accept a fitness standard that limits employment to athletes.

If task relevance is a prerequisite for setting a fitness standard for fire fighters, then one must come to grips with identifying the task and then determine the lowest performance level of that task that would be acceptable. Air Force fire chiefs have established a variety of fire fighting tasks that are included in the mandatory training program for their fire fighters, and the standardized structural rescue task studied here is among the most, if not the most, physically demanding of all of them. Thus, the successful performance of this task predicts that the fire fighter will certainly be physically capable of performing less strenuous tasks as well. Although it may be difficult to achieve a consensus from fire chiefs with respect to a maximum allowable time for this, or any other performance task, there should be no question whatsoever that the fire fighters who unequivocally failed in the Air Force structural rescue task would represent a high probability of failure at other tasks requiring physical fitness. In studying fire fighter performance in the standardized Air Force structural rescue task, 23 fire fighters quit with complaints of excessive fatigue/exhaustion before they could complete the task. From the standpoint of physical fitness, it is not just a coincidence that the aerobic capacity of these failures averaged only 29 ±7.1 $ml \cdot kg^{-1} \cdot min^{-1}$ (2510 ±904 $ml \cdot min^{-1}$). The fact that, in Table 3 it was noted that the 5 poorest of these 23 failures exhibited an aerobic capacity averaging only 25.0 ±2.0 $ml \cdot kg^{-1} \cdot min^{-1}$, is further evidence of the performance liability accompanying low levels of cardiovascular fitness. Regardless of whether or not agreement emerges within the fire protection community with respect to time standards for any of a number of possible simulated fire fighting tasks, the fire fighters who were unable to complete the task at all must still be considered as "failures".

If a $\dot{V}O_{2\,max}$ of 29 $ml \cdot kg^{-1} \cdot min^{-1}$ should be accepted as a failure, the next step would be to determine the fitness level that predicts success in occupational tasks. O'Connel et al.[16] and Davis et al.[17] have recommended values of 39.0 and 42.0 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively, as the minimum $\dot{V}O_{2\,max}$ standard for fire fighters. For discussion purposes, it is suggested that a time of 5 minutes be considered as the slowest acceptable performance for the standardized rescue task studied here. The rationale for selecting this level include the following: (1) it was suggested by the fire chiefs who supervised their fire fighters during the performance of this task; (2) this is a level of performance already demonstrated by more than about 50% of the career (mostly sedentary) fire fighters studied, i.e., those with only "average" levels of physical fitness were able to meet this standard; and (3) fire fighters who are not physically capable of such a performance--but are in normal health--are known to be capable of improvements in $\dot{V}O_{2\,max}$ up to 30% within 16 weeks of structured on-duty fitness conditioning[16,17]. It is suggested that most of these (i.e., normally healthy) fire fighters would be able to train up to this modest standard

(i.e.,table 8 suggests that a $\dot{V}O_2\,max$ of 36 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ will support a rescue task performance of $\leq$ 5 minutes)

Considering the suggested rescue task performance standard of $\leq$ 5 minute in the present study, over 50% of the fire fighters studied here would fail to meet this requirement. A more detailed breakout of failure rate as a function of aerobic capacity is shown in Table 8.

Table 8. Probability of failure in rescue task performance (i.e., > 5 minutes) for fire fighters as a function of aerobic capacity in $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ or in $ml{\cdot}min^{-1}$.

$\dot{V}O_2\,max$ $ml{\cdot}kg^{-1}{\cdot}min^{-1}$	n	% Failure	$\dot{V}O_2\,max$ $ml{\cdot}min^{-1}$	n	% Failure
18-25	12	100	1500-2000	11	82
26-30	33	82	2001-2500	31	87
31-35	30	87	2501-2900	34	68
36-40	46	46	2901-3200	37	60
41-45	38	37	3201-3500	35	40
46-50	22	27	3501-3800	27	33
51-55	29	35	3801-4100	16	38
56+	12	0	4101-4500	18	17
			4501+	11	27

Table 8 describes how the measures of $\dot{V}O_2\,max$ alone corresponded with task success or failure in this study. For example, if it was desired to select a value for $\dot{V}O_2\,max$ below which more than 50% of the fire fighters tested failed, that value would be either 36 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ or 3201 $ml{\cdot}min^{-1}$. A similar approach to identifying measures of strength that corresponded with success and failure in this sample of fire fighters is presented in Table 9.

Table 9. Probability of failure in rescue task performance (i.e., > 5 minutes) for fire fighters as a function of arm strength.

Row (lbs)	n	% Failure	Bench Press (80-lb reps)	n	% Failure
<75	23	87	≤10	9	100
75-85	21	52	11-20	29	62
86-95	26	81	21-30	61	53
96-100	34	32	31-40	34	35
>100	57	35	> 40	31	32

From Table 9 it can be seen that although individual variability is evident, as strength increases the percentage of failures in the rescue task tends to decrease. Most obvious in this table is the observation of 100% failure for the fire fighters who were unable to complete at least 11 repetitions for the 80-lb bench press.

If fire protection professionals can reach an agreement as to the slowest acceptable time for completing this structural rescue task, then the formula described in this paper can provide guidance as to the minimal levels of cardiovascular fitness, muscular strength, and lean body mass that can best predict

that time standard. For example, Table 10 shows the fitness standards that were computed when applying this formula to the hypothetical time standard of 5 minutes for this rescue task.

Table 10. Examples (derived from multiple regression equations) of combinations of scores for body composition and fitness measures needed to predict a performance of 5 minutes for the Air Force fire fighter structural rescue task.

$\dot{V}O_2$ max, ml·min^{-1}

% Body Fat	Muscular Strength (maximum curl lift, lbs)						
	40	60	80	100	120	140	160
10	3387	2868	2349	1830			
15	3984	3464	2945	2426	1907		
20	4580	4061	3542	3023	2504	1985	
25		4658	4139	3620	3101	2581	
30			4735	4216	3697	3178	2659
35				4813	4294	3775	3256
40					4890	4372	3852

It should be emphasized that, as with any modeling of biological systems, there will be individuals who do not fit the model. That is, some individuals may be able to complete the task in the required time even though they don't meet the physical standards, and vice-versa. However, from the standpoint of statistical probability, Table 10 provides some examples for the application of the regression formula for predicting combinations of physical requirements that correspond with the physical capability to perform the standardized Air Force fire fighter structural rescue task. For example, a fire fighter of any gender or age with a fat content of 10% of body weight and an aerobic capacity of 2349 ml·min^{-1} must demonstrate the ability to curl an 80-lb bar bell if he/she can be expected to complete the rescue task in $\leq$ 5 minutes. However, if that fire fighter's strength decreased to 60-lbs for the curl, his/her aerobic capacity would need to increase to 2868 ml·min^{-1} to meet this same 5 minute time requirement. As with many regression equations for predicting human performance, the mathematical generation of numbers can lead to nonsensical values. For example, should a fire fighter with 10% body fat decondition to the point where $\dot{V}O_{2\,max}$ drops to 1310 ml·min^{-1}, the equation suggests that increasing curling strength to 120 lbs would still predict a performance of $\leq$ 5 minutes. The chances that a fire fighter with such a low aerobic capacity could complete this task at all is so near to physiologically impossible that it, and other extremes which could be calculated from this regression equation, are omitted from consideration in this table.

Recommendations

Fire protection specialists should review the results of this study to determine whether or not the performance task validly represents at least some of the emergency duties expected of fire fighters. If that is agreed, it is recommended that they reach agreement as to the slowest acceptable performance time for this task and then apply a regression formula similar to that suggested in Table 7 as a guide for determining minimal acceptable levels of cardiovascular fitness, muscular strength, and lean body mass for fire fighters who may be called upon to perform these tasks. It is recommended that applicants be held to a higher standard because of the abundance of evidence that (1) fitness decreases with age; and (2) higher levels of fitness translate to better performance, at reduced risk.

As an interim suggestion, it is recommended that an aerobic capacity of 36 $ml \cdot kg^{-1} \cdot min^{-1}$ be considered as the minimum acceptable standard for qualifying a fire fighter for strenuous rescue tasks. Data from the literature and from the present study which provide rationale for this suggestion include the following:

1. At least 50% of the fire fighters with a $\dot{V}O_2\,max$ of 36-40 $ml \cdot kg^{-1} \cdot min^{-1}$ completed the standardized Air Force rescue task in $\leq$ 5 minutes (Table 8).

2. An aerobic capacity of $\geq$ 36 $ml \cdot kg^{-1} \cdot min^{-1}$ is reasonable and achievable.

a. The $\dot{V}O_2\,max$ of the average military fire fighter weighing 83.5 kg is 39.4 $ml \cdot kg^{-1} \cdot min^{-1}$ (Table 2), while those in the quartile immediately below the midpoint in performance scores weighed 87.4 kg and have a mean $\dot{V}O_2\,max$ of 36.0 $ml \cdot kg^{-1} \cdot min^{-1}$ (Table 5).

b. Aerobic capacity declines steadily with age in a sedentary population, and the rate of decline observed in the present study suggests that the average fire fighter beyond 39 years would not meet this standard. However, previous studies[18,19] have demonstrated that, when deconditioned fire fighters participate in a personalized on-duty aerobic exercise program, increases in $\dot{V}O_2\,max$ of from 15% to 30% can be expected within the first 16 weeks of training. Since the aerobic capacity for a sedentary population of males aged 40-49 years averages 31.2 $ml \cdot kg^{-1} \cdot min^{-1}$ [18] such deconditioned individuals (i.e., about half of the sedentary male population) could achieve 36+ $ml \cdot kg^{-1} \cdot min^{-1}$ with proper on-duty conditioning exercise within 16 weeks[18,19].

c. There is no evidence to suggest that a normal, healthy adult - who has lost cardiovascular fitness through lack of exercise and/or excessive weight gain - would be unable to steadily improve aerobic capacity with a disciplined adherence to a safe and reasonable training regimen. Although the rate of gain can be expected to be greater for those who have deteriorated to the lowest levels, achieving a standard of 36 $ml \cdot kg^{-1} \cdot min^{-1}$ may require time commensurate with the extent of that deterioration, but again, only the failure to participate in a professionally prescribed program would preclude achieving that goal.

It is recommended that fire protection administrators convene to establish fair but meaningful fitness standards for career fire fighters that are both age and gender blind. Further, it is recommended that: (1) "minimal standards" be distinguished from reasonable fitness "goals"; (2) that the fire department provide an on-duty fitness conditioning program; and (3) that a reasonable time be allowed for each incumbent fire fighter to reach compliance with fitness standards to help reduce the relatively rapid rate of decline in fitness known to occur with aging in a sedentary population.

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Appendix

Double victim rescue study. The physical characteristics of the fifty-four male and three female career fire fighters who participated in this study are summarized in Table 1.

Table 1. Summary of physical characteristics and task performance data for subjects performing the double victim rescue exercises (n = 57).

	Mean	Std Dev	Minimum	Maximum
Age, years	27.4	8.5	19	56
Ht, cm	178.4	7.3	164.3	195.6
Wt, kg	80.9	9.6	59.0	102.1
Body fat, %	19.4	4.9	9.7	31.6
$\dot{V}O_2$ max, $ml{\cdot}kg^{-1}{\cdot}min^{-1}$	44.2	9.3	27.8	65.0
Bench press, lbs	157.4	43.5	60.0	285.0
Leg press, lbs	422.1	99.4	240.0	750.0
Curl, lbs	82.2	18.7	30	110
Row, lbs	97.8	21.6	40.0	140.0
80 lb bench press, reps	25.2	12.0	0	55
Performance Data:				
Total rescue time, sec	892.9	518.5	182	1800
Peak exercise heart rate	188.4	9.4	168	208
Ventilation, $l{\cdot}min^{-1}$ (ATPD)	87.2	18.0	50.1	125.1

From Table 1 it can be seen that the fire fighters participating in this study ranged in age from 19 to 56 years, and the mean for the group was 27.4 years. The cardiovascular fitness ($\dot{V}O_2$ max) of these subjects, as estimated by submaximal cycle ergometry averaged 44.2 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, but varied from a low of 27.8 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ to a high of 65.0 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. This, combined with a rather wide variation in scores for percent body fat and strength, is evidence that this group exhibits considerable diversity with respect to physical fitness. Notable among the performance data were the mean values for peak heart rate and ventilatory minute volume which were 188.4 beats per minute (bpm) and 87.2 $l{\cdot}min^{-1}$, respectively. The physical exertion required to complete this task becomes dramatically evident when it is realized that the peak heart rate observed represents 98% of the estimated maximal heart rate (i.e., maximal heart rate = 220 - age) for this group. The calculated mean time of 893 sec for completing this task may not be of practical value for many reasons. Attempts to correlate fitness variables with task performance times presented a challenge when it became evident that most of male (67%) and all of the female fire fighters failed to complete this task. One approach was to settle upon a rescue time which might be considered as the criterion for a successful performance and then to compare the physical characteristics of the successful vs. the failing fire fighters. Thus, the best time (182 sec.) achieved by a fire fighter within this group was established as a reference for excellence. Then, the time of 600 sec was selected in this first attempt to establish the maximum time allowed for a "successful" performance. The data in Table 2 were then rearranged to represent the characteristics of "successful" vs. "failing" fire fighters.

Table 2. Summary of time as a function of selected physical fitness variables for successful vs. failing fire fighters performing a simulated emergency double victim rescue task.

Variable	Mean ± SD Pass (n = 16)	Mean ± SD Fail (n = 41)		Best Performance (G.R., Grand Forks AFB)
Age, yrs	27.5 ±6.6	27.4 ±9.3		27
Ht, cm	183.1 ±6.1	176.6 ±7.0		195.6
Wt, kg	83.1 ±9.1	80.0 ±9.8		97.1
Fat, %	18.0 ±3.2	19.8 ±5.3		13.7
$\dot{V}O_2$ max, ml·kg^{-1}·min^{-1}	53.8 ±5.6	40.5 ±7.7		63.9
Bench press, lbs	183.3 ±40.6	146.4 ±40.4		158
Leg press, lbs	482.1±115.0	398.0 ±82.3		533
Curl, lbs	96.3 ±11.5	76.4 ±18.1		110
Row, lbs	111.9 ±15.2	92.1 ±21.3		120
80# bench press, reps	32.6 ±11.3	22.2 ±11.1		33
Reach victim, min:sec	1:30.4 ±0:17.4	1:52.6 ±0:28.6		
Drag victim, min:sec	2:16.2± 0:31.1	4:49.4± 2:02.7		
Time (victim #1), min:sec	3:46.6 ±48.5	6:42.0 ±2:31.3		93
Total time, min:sec	7:53.4 ±1:36.4	19:21.4 ±8:20.0	(n = 25)	182
Peak exercise heart rate	178.0 ±11.0	188.4 ±9.4		--
Ventilation, l·min^{-1}	94.5±14.8	---		--

From Table 2 it can be seen that only 16 or 28% of the fire fighters studied were able to complete this two-victim rescue task in $\leq$ 10 minutes. It should also be noted that only 25 of the 41 failing fire fighters who started the two-victim rescue task were able to even begin an attempt to rescue the second victim. It is difficult to estimate a performance time for fire fighters who were unable to begin the second rescue, but mean times for rescuing victim #1 were 227 sec and 402 sec for the successes and the failures, respectively. Although the mean age for the successful and failing groups was identical, the successful fire fighters exhibited significantly higher scores in all fitness parameters except percent body fat. The fire fighter achieving the best performance exhibited also, not surprisingly, the second highest level of aerobic capacity (63.9 ml·kg^{-1}·min^{-1}) and he was also leaner (13.7 vs. 19.4 % fat) and demonstrated greater strength than the averages for the group.

The low rate of success observed for the two-victim rescue task, either in terms of an acceptable time or indeed in just completing the task, became worrisome for both the participating fire chiefs and the investigators in this study. This prompted a revision of the protocol to require only a single-victim rescue in the hope that fitness and measurable performance data would be procurable from a sample population that would be large enough to facilitate more valid statistical analyses. Two Hundred and eighteen male and four female fire fighters representing one Army and seven Air Force fire departments participated in this single-rescue performance study; The results of that study are summarized in the main body of this paper.